Optimal Asset Distribution for Environmental Assessment and Forecasting Based on Observations, Adaptive Sampling, and Numerical Prediction

Steven R. Ramp
Monterey Bay Aquarium Research Institute
7700 Sandholdt Road
Moss Landing, CA 95039
phone: (831) 775-2126 fax: (831) 775-1620 email: sramp@mbari.org

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LONG-TERM GOAL

The long-term goal is to enhance our understanding of coastal oceanography by means of applying simple dynamical theories to high-quality observations obtained in the field. My primary area of expertise is physical oceanography, but I also enjoy collaborating with biological, chemical, acoustical, and optical oceanographers to work on interdisciplinary problems. I collaborate frequently with numerical modelers to improve our predictive capabilities of Navy-relevant parameters in the littoral zone.

OBJECTIVES

The objective of this Multi-University Research Initiative (MURI) grant, subtitled, "The Adaptive Sampling and Prediction System (ASAP)" is to learn how to deploy, direct, and utilize autonomous vehicles [and other mobile sensing platforms] most efficiently to sample the ocean, assimilate the data into numerical models in real or near-real time, and predict future conditions with minimal error. The scientific goal is to close the heat budget for a control volume surrounding a three-dimensional coastal upwelling center, and identify via the magnitude of the terms the relative importance of the surface fluxes, boundary layer processes, alongshore advection, and mesoscale interactions in determining the temperature changes within the box.

APPROACH

The mobile assets for this project included 10 gliders (6 Slocum vehicles from WHOI and 4 Spray vehicles from SIO), 3 propeller-driven vehicles (DORADO from MBARI and 2 Odysseys from MIT), a research aircraft (NPS TWIN OTTER) and several support ships (SHANA RAE, POINT SUR, ZEPHYR, SPROUL, NEW HORIZON). Given these resources and the objectives above, a control volume (Figure 1) was selected for the 2006 experiment. The box, approximately 40 x 20 km, enclosed the upwelling center that is of central scientific interest. Six gliders were deployed along "racetracks" within the box and 4 were deployed as "rockers" oscillating back-and-forth along the boundaries, one on each end and two covering the offshore side. Using a combination of autonomous and human-activated control, the gliders were coordinated as a group to optimize the sampling coverage of the control volume in response to the ever-changing current conditions. A pair of bottom-mounted acoustic Doppler current

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14. ABSTRACT
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profilers (ADCPs) was also deployed along the southern boundary of the box to sample and report the internal wave environment in real time via a Seaweb underwater network.

The real-time observations were ingested into the NCOM, HOPS, and ROMS numerical ocean models each evening for predictive runs for the following day. Assets were then re-allocated to optimize sampling coverage and minimize model predictive error. See also annual report of the same name by Prof. Naomi Leonard of Princeton, for more detail on the coordinated control, adaptive sampling, and numerical prediction aspects of this program.

WORK COMPLETED

The field program for August 2006 was a great success (see last year's annual report for a complete description). This year the emphasis switched to analysis, synthesis, and publication of the results. A workshop was held in Woods Hole, MA during June 2008. The investigator also visited R. E. Davis at SIO for a few days to collaborate on the glilder/mooring comparisons and the heat flux problem. Progress this year was hampered somewhat by the PI's relocation to a new institution, by the sudden death of my wife in February 2008, and by the extreme lateness of the funds which did not arrive until July 30, 2008. Nevertheless we did manage to make some progress, mostly on extended funds from last year. This was primarily in the technical areas of glider/mooring and model/data comparisons as described below.

RESULTS

While glider-observed integrated velocities have been compared to other observing technologies in deep water, there has been little work done in water depths less than 100 m, where boundary layer flows and fractionally more time spent on the surface may corrupt glider-sampled vertically integrated velocities. Glider-sampled velocities were systematically compared to vertically averaged velocities from ADCP moorings for all profiles within 5 km of a mooring. Results were poor for outside 3 km so these were eliminated from further study. Individual vector comparisons were generally very good (Figure 2) although there were occasionally cases with no agreement at all, which are being investigated further. Speed error increased with absolute speed while direction error decreased to near zero for speeds greater than 8 cm s^{-1} (Figure 3).

An overview paper similar to the one for AOSN-II [Ramp et al., 2008a] was also written for the 2006 experiment [Ramp et al., 2008b]. This paper however placed a larger emphasis on comparing the three ASAP numerical models to the two ADCP moorings (Figure 4). Correlations between the observations and local buoy winds indicate that the currents over the shelf were remotely-forced much of the time. Spatial and temporal correlations and least-square error calculations between the various models and the observed currents showed that the HOPS nested model performed marginally better than the others, and all three models struggled during the second half of the experiment when the currents were remotely rather than locally forced. This indicated the importance of having correct boundary conditions from the outer domains of these multiply-nested models. The paper is an expansion of a Master's thesis by ENS Rebecca Wolf, USN [Wolf, 2007].

IMPACT/APPLICATION

All recent Navy METOC publications indicate that autonomous vehicles are the way of the future in battlespace environmental assessment. The Naval Oceanographic Office has already initiated procurement of large numbers of gliders and significant numbers of propeller-driven vehicles. Experiments such as ASAP will help the Navy to learn how to utilize these vehicles most effectively, to maximize the information returned, and to assimilate the data into numerical models for environmental prediction.

This project had wide impact in the education and ocean outreach communities. The principal investigator was an invited speaker at the ASAP media and VIP information days, appeared on National Public Radio in both Monterey and Santa Cruz, and appeared live on the Daily Planet, broadcast world-wide by the Discovery Channel Canada.

TRANSITIONS

The virtual control room (COOP) has been used to support several subsequent Navy field experiments and will be used again for the MB08 “Oktoberfest” experiment. Collaborative control of fleets of autonomous vehicles is being considered for use in the national Integrated Ocean Observing System (IOOS) as it minimizes daily human-in-the-loop interactions and reduces costs for long-term ocean monitoring.

RELATED PROJECTS

See ONR Annual Report by Naomi Leonard (Princeton)
See ONR Annual Report by Jim Bellingham (MBARI)
Persistent Litoral Undersea Surveilance network (PLUSnet)
Assessing the Effects of Submesoscale Ocean Parameterizations (AESOP)
Layered Organization of the Coastal Ocean (LOCO)
NRL BIOSPACE Experiment summer 2008
MB08 “Oktoberfest” ocean color and harmful algal bloom experiment

PUBLICATIONS

Ramp, S. R., R. E. Davis, N. E. Leonard, I. Shulman, Y. Chao, A. R. Robinson, J. Marsden, P. Lermusiaux, D. Fratantoni, J. D. Paduan, F. Chavez, F. L. Bahr, X. S. Liang, W. Leslie, and Z. Li, 2008a: Preparing to predict: The second Autonomous Ocean Sampling Network (AOSN-II) experiment in the Monterey Bay. *Deep-Sea Research II*, in press.

Ramp, S. R., P. Lermusiaux, I. Shulman, Y. Chao, R. E. Wolf, and F. L. Bahr, 2008b: Oceanographic and atmospheric conditions on the continental shelf north of the Monterey Bay during August 2006. For submission to JGR. Completed, being reviewed by co-authors.

Wolf, R. E., 2007: Observations and modeling of the shelf circulation north of the Monterey Bay during August 2006. MS Thesis, Naval Postgraduate School

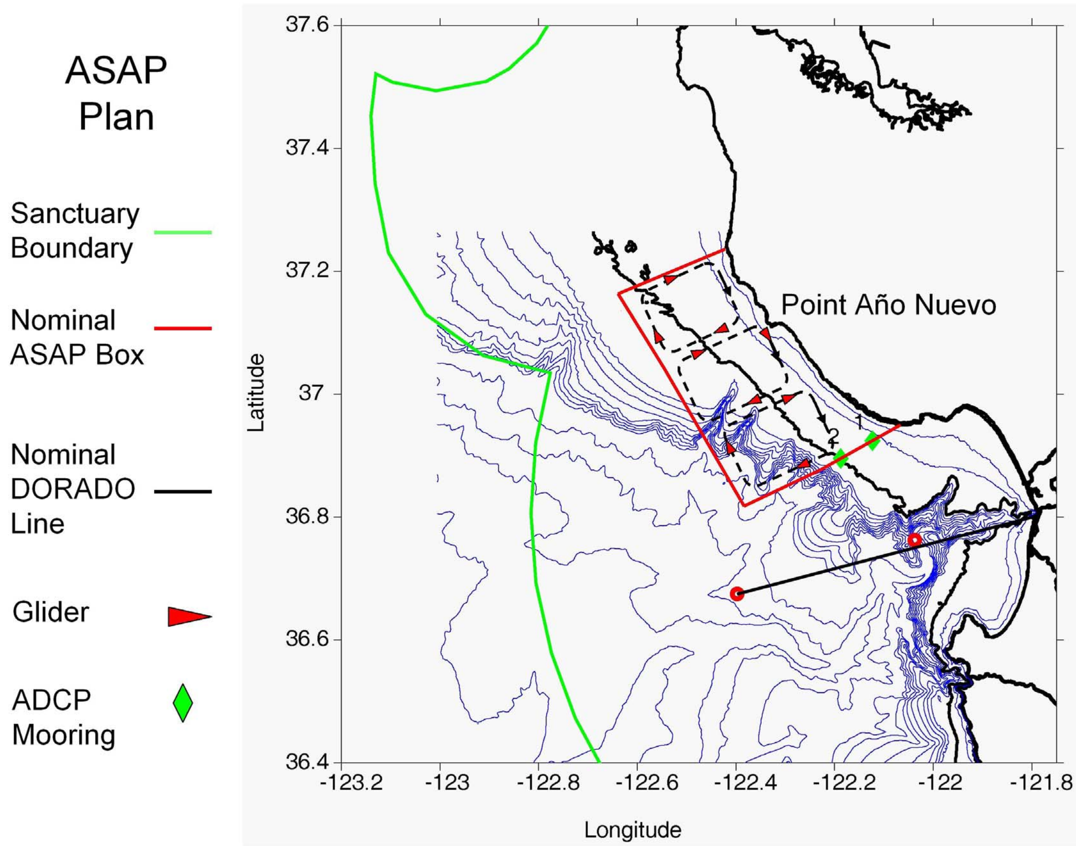

Figure 1. Experiment location showing the ASAP sample box (red), glider racetracks (dotted), the DORADO line (black) and the bottom-mounted real-time acoustic Doppler current profilers (green diamonds).

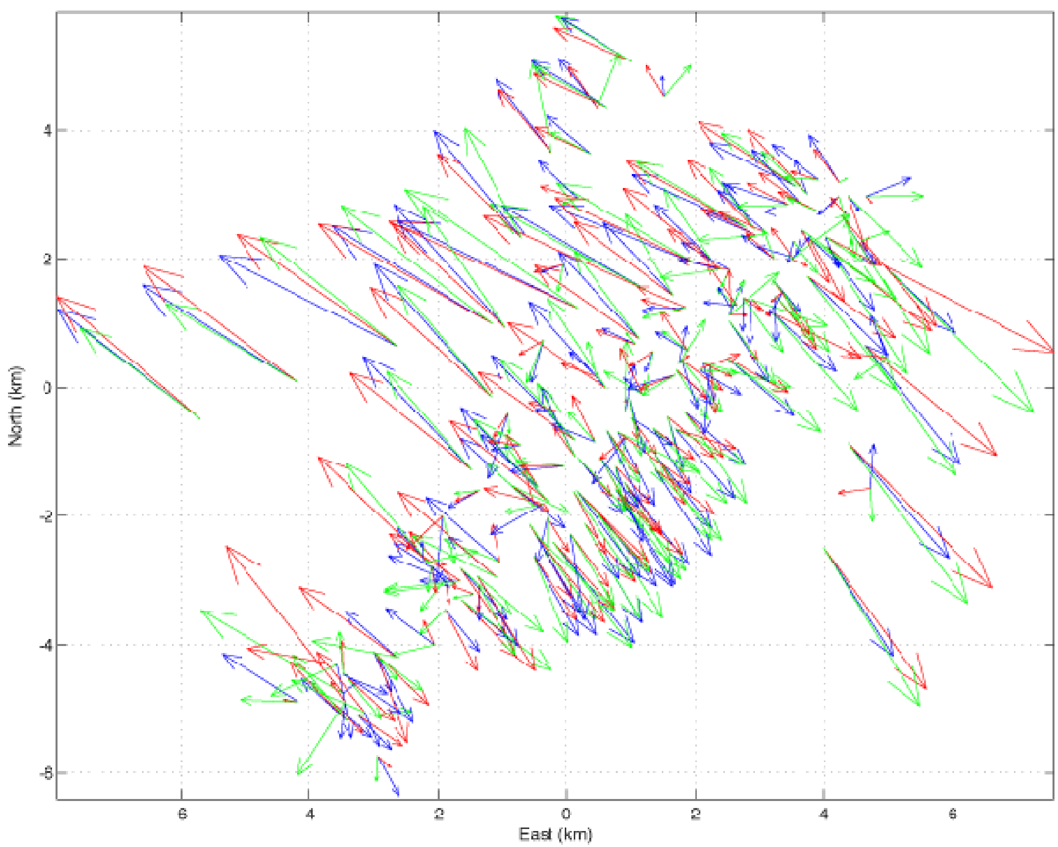

Figure 2. A comparison of velocity vectors from gliders (blue) with vertically-averaged ADCP data from site 2 during the same time (red) and the same data extended to the surface using persistence (green).

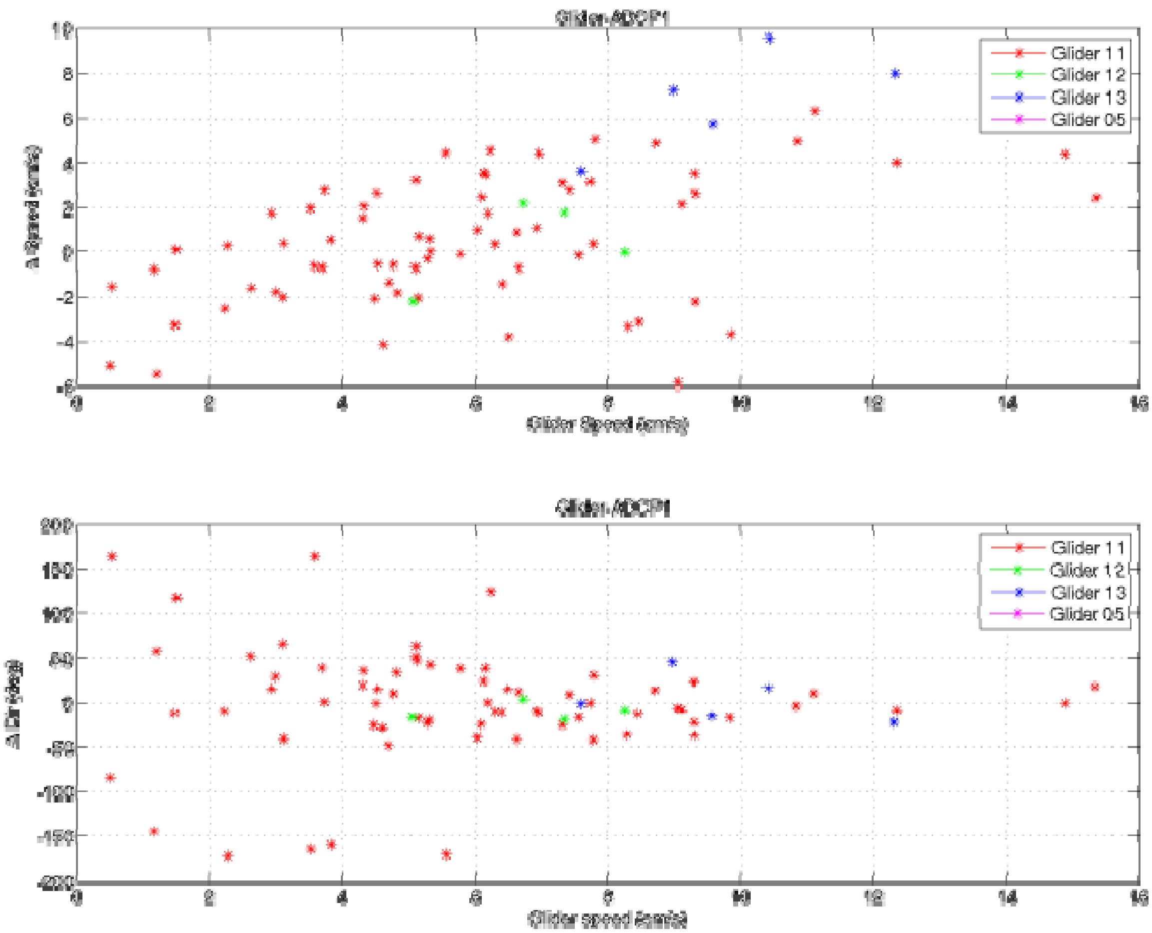

Figure 3. Glider/mooring differences at site ADCP 1 for speed (top) and direction (bottom). Speed error increased with absolute speed while directional differences improved.

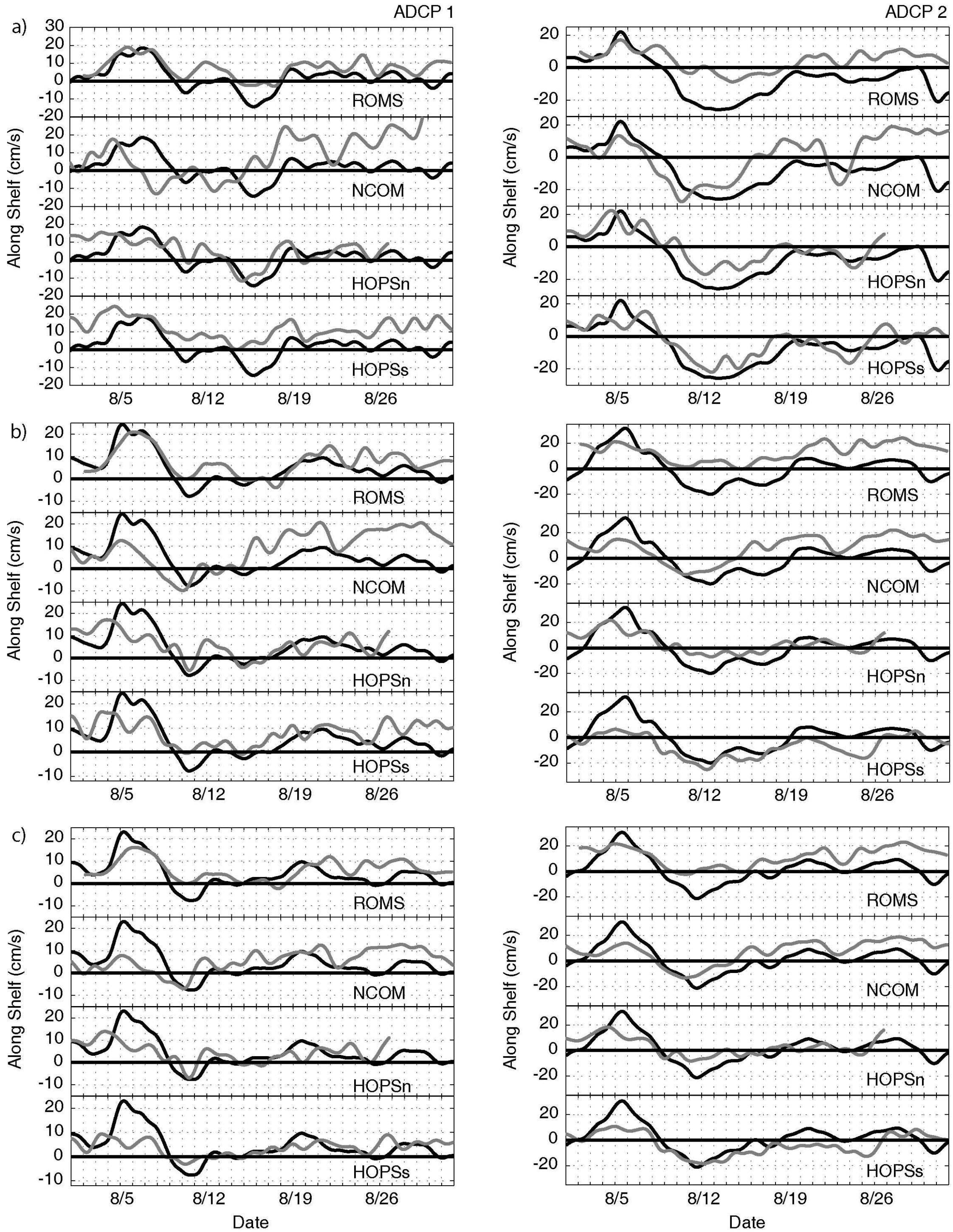

Figure 4. Model/data (gray/black lines) comparisons for the alongshore current components at ADCP 1 (left column) and ADCP 2 (right column). The three vertical panels for both columns are the comparisons for a) near-surface (10, 12 m), b) mid-depth (24, 52 m), and c) near-bottom (46, 72 m).